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Methods for Co-modelling and Analyzing Packet Networks Operating ov r Optical Networks

Related Applications

This application claims priority from U.S.

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Field of the Invention

The invention relates to methods of co-modelling
and analyzing packet networks that operate over optical
10 networks.

Background of the Invention

Increasingly, Internet Protocol/Multiprotocol
Label Switching (IP/MPLS) networks must be able to support
high availability services such as voice transmission. In
15 order to meet this requirement on their own, IP/MPLS
networks, comprising a packet network and an underlying
optical network, must be able to achieve the level of
reliability and maintenance traditionally available in
transport networks. One aspect of providing this
20 reliability is deciding in which network packet link
protection should be implemented.

In response to this dilemma, protection mechanisms
operating in the packet network such as MPLS fast reroute
have been designed that can protect services in time frames
25 equivalent to Synchronous Optical Networks (SONET) automatic
protection switching once a failure has been detected. Like
any other similar scheme, MPLS fast reroute is required to
maintain additional protection-specific bandwidth.

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In parallel to advances developed in the protection of packet networks, optical networks have also evolved to support new types of architectures and protection schemes. These schemes, such as mesh protection, have been
5 designed to be more flexible and efficient.

The development of improved protection methods in both optical networks and packet networks has created an opportunity for service and network engineers to choose how to best implement packet link protection.

10 When trying to decide how and where to implement packet link protection in a packet transport network, one criterion worth examining is the bandwidth requirement of each method of protection.

If packet link protection is completely handled by
15 the packet network, no protection is required in the optical network. Therefore the packet network can use an unprotected optical connection service. If a packet link is protected by the optical network, then MPLS fast reroute or an alternative protection scheme is not required in the packet
20 network. Using the full complement of both MPLS fast reroute and optical mesh protection results in a waste of resources.

Summary of the Invention

Examining bandwidth requirements of packet protection schemes performed in the packet network, or the
25 optical network allows a user to evaluate different factors related to a resulting packet transport network. For example, determining the cost of a resulting packet transport network using separate methods of packet link protection could fundamentally affect a strategy for
30 designing a new packet transport network or modifying an existing packet transport network.

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Prior to examining packet protection schemes it is necessary to co-model a packet network operating over an optical network. A method for co-modelling the packet network and optical network involves using information that

5   describes network routers and how they are interconnected and information that describes traffic that flows in and out of the packet network are used to assign packet capacity to the various packet links between routers. The packet capacity output and information that describes optical

10 cross-connects which provide access to the optical network from the network routers and how they are interconnected are then used to assign optical capacity to the various optical links in the optical network. This results in a simulated packet transport network output which details capacity

15 information regarding the packet network and the optical network. This output may than be used to analyze or examine different aspects of the simulated packet transport network. For example, analysis of the resulting simulated packet transport network can include evaluation of protection

20 requirements by performing survivability analysis. It can also include network capacity planning.

A survivability analysis on the network allows a user to simulate a failure of any single optical link in the simulated packet transport network and examine how this

25 affects the traffic carrying requirements of the network. The invention provides methods for performing survivability analysis that can be performed on either the packet network or the optical network of the output simulated packet transport network.

30   The co-modelling of the packet and optical networks and further analysis are implemented by computer algorithms. The computer algorithms may perform only the aspect of generating the simulated packet transport network,

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may perform only analysis on the simulated packet transport network output, or may perform both the generation of the simulated packet transport network and analysis on the output.

5   Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

Brief Description of the Drawings

10   Preferred embodiments of the invention will now be described with reference to the attached drawings in which:

         Figure 1 is a schematic depicting a portion of a packet network which uses Multiprotocol Label Switching

15 (MPLS) fast reroute as a packet link protection scheme;

         Figure 2 is a schematic depicting a portion of an optical network which uses optical mesh protection as a packet link protection scheme;

         Figure 3 is a schematic showing a portion of a

20 packet transport network comprised of a packet network and an underlying optical network;

         Figure 4 is a flow diagram which demonstrates the steps involved with co-modelling a packet network and an optical network;

25   Figure 5 is a schematic showing a portion of a simulated packet transport network based on Figure 3, which demonstrates the representative inputs and outputs used in the steps of Figure 4;

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Figure 6A is a schematic of a representation of a packet network topology us d as an input to the flow diagram of Figure 4.

Figure 6B is a schematic of a representation of an
5 optical network topology used as an input to the flow diagram of Figure 4.

Figure 7 is a flow chart which expands upon a step of flow assignment of a packet network as introduced in Figure 4;

10 Figure 8 is a flow chart which expands upon a step of flow assignment of an optical network as introduced in Figure 4;

Figure 9 is a flow chart for performing survivability analysis on a combined packet network and
15 optical network;

Figure 10 is a flow chart for performing survivability analysis on a combined packet network and optical network using MPLS fast reroute protection; and

Figure 11 is a flow chart for performing
20 survivability analysis on a combined packet network and optical network using optical mesh protection.

Detailed Description of the Preferred Embodiments

MPLS fast reroute is a localized packet link protection mechanism for use within a packet network. An
25 example of how MPLS fast reroute works is demonstrated in Figure 1. A portion of a packet network 10 is shown to be comprised of a protected packet link 11 containing at least one Label Switched Path (LSP) 16, a back-up LSP tunnel 14 and first and second routers 12,13. The first router 12 is

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connected to the second router 13 by the protected packet
link 11. The first router 12 and the second router 13 are
also connected by the back-up LSP tunnel 14. A failure 15 is
located on the protected packet link 11.

5   In normal operation, when the protected packet
link 11 between the routers 12,13 is configured, the MPLS
fast reroute protocol establishes an alternative shortest
route packet link around the protected packet link 11, which
is the back-up LSP tunnel 14.

10   In the operational stage depicted in Figure 1, the
failure 15 of the protected packet link 11 is detected and
fault information is propagated to the first router 12. The
at least one LSP 16 normally carried by the protected packet
link 11 is encapsulated and re-routed to the back-up LSP
15 tunnel 14 at the first router 12. The at least one LSP 16
that is re-routed and carried on the back-up LSP tunnel 14
is un-encapsulated at the second router 13.

          It is important to ensure that there is enough
bandwidth capacity on the route established as the back-up
20 LSP tunnel to accommodate the packets that are re-routed. If
not enough capacity can be found on the shortest back-up
route, then more than one back-up tunnel can be configured,
using different routes. This allows for a general condition
that there can be more than one back-up LSP tunnel per
25 protected packet link. However, it is critical that none of
the back-up tunnels be part of the same shared risk link
group as the protected packet link. That is, they should not
use the same underlying optical links.

          MPLS fast reroute implementations achieve the 50
30 ms switch-over time required by high availability
applications.

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Optical mesh protection operates on the basis of end-to-end optical paths. Figure 2 shows an example of packet link protection in an optical network using optical mesh protection. A portion of an optical network 20 contains
5   a working tunnel 25, a protection tunnel 23 and fist and second optical mesh protection cross-connect switches 21,22. The working tunnel 25 is connected between the first optical mesh protection cross-connect switch 21 and the second optical mesh protection cross-connect switch 22 via a third
10   optical mesh protection cross-connect switch 28. The protection tunnel 23 is also connected between the first optical mesh protection cross-connect switch 21 and the second optical mesh protection cross-connect switch 22. In this example, the protection tunnel 23 is routed through a
15   fourth optical mesh protection cross-connect switch 29. The working tunnel 25 and the protection tunnel 23 each have an associated control channel (not shown).

During normal operation the working tunnel 25 is configured to support optical connections between the two
20   optical mesh protection cross-connect switches 21,22 via an optical path, in this example the optical path includes a first optical link 26, the third optical mesh protection cross-connect switch 28 and a second optical link 27. When an optical link failure 24 occurs as shown in Figure 2,
25   fault information is propagated along the control channel of the working tunnel 25. The optical mesh protection cross-connect switches 21,22 at both ends of the optical path perform the switch-over of optical connections from the working tunnel 25 to the protection tunnel 23. Proper
30   synchronization of a signal being transmitted is maintained using the control channel of the protection tunnel 23.

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Under a conventional assumption of a single
failure, it is possible for two or more working tunnels to
share the same protection tunnel in whole or in part.

Following the optical link failure 24 of the
5   working tunnel 25 and a switch-over to the protection tunnel
23, it is possible to temporarily establish another
protection tunnel in order to cover the rare case of double
failure.

The protection tunnel 23 is released once the
10   optical link failure 24 is repaired and the working tunnel
25 is re-established.

When determining the best manner of packet link
protection for a specific situation it is valuable to
evaluate the protection schemes based on various criteria.
15   One important criterion to examine is the bandwidth
requirement of each method of protection. Modelling a packet
transport network comprising both the packet and optical
networks allows a user to evaluate different system
conditions and compare resulting bandwidth requirements for
20   various methods of packet link protection.

Figure 3 depicts an overall view of a packet
transport network 30 comprising both a packet network 31 and
an optical network 32. The packet network 31 is similar to
that which is represented in Figure 1. The optical network
25   32 is similar to that which is represented in Figure 2.
There are three distinct segments used as optical
connections within the optical network 32 when communicating
with the packet network 31. The three segments include two
access links 33,34 and an optical path 35.

30   A first access link 33 connects the first router
12 located in the packet network 31 to the first optical

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mesh protection cross-connect switch 21 located in the optical network 32. The optical path 35 connects the first optical mesh protection cross-connect switch 21 to the second optical mesh protection cross-connect switch 22. In
5   this example, the optical path 35 includes the third optical mesh protection cross-connect switch 28 and the first and second optical links 26,27 which are all located in the optical network 32. A second access link 34 connects the second optical mesh protection cross-connect switch 22 to
10 the second router 13 that is located in the packet network 31. The packet link 11 connects the first and second routers 12,13 in the packet network 31.

       Figure 4 illustrates a main process 40 in which steps are used to co-model a packet network and an optical
15 network wherein the packet network is operated over the optical network. The main process 40 requires three supplied inputs. A first input is a packet network topology 42 including information such as a number of routers in the packet network, placement of router links and other
20 pertinent information regarding the packet network. A second input is a packet traffic matrix 41, which defines data flow and bandwidth requirements in and out of the packet network. A third input is an optical network topology 43 including information such as a number of
25 optical cross connect switches in the optical network, placement of optical links and other pertinent information regarding the optical network. A user supplies the three inputs 41,42,43. In some embodiments provided by the invention the three inputs 41,42,43 are generated by the
30 user according to the desired topology of an overall network that is being modelled and the traffic flow in and out of the packet network.

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Flow assignment for the packet network 44 is a multi-step sub-process of the main process 40 that establishes the flow and bandwidth capacity capable of being carried on the packets links of the packet network. The
5   inputs to the flow assignment for the packet network 44 are the packet network topology 42 and the packet traffic matrix 41.   The resultant output of the flow assignment for the packet network 44 is a simulated packet network comprising information regarding data flow and bandwidth capacity for
10   the packet network so as to create a basic packet capacity 45 for packet links in the packet network.

Flow assignment for the optical network 46 is another multi-step sub-process of the main process 40 that establishes the flow and bandwidth capacity capable of being
15   carried on the optical links of the optical network. The inputs to the flow assignment for the optical network 46 are the basic packet capacity 45 of the simulated packet network and the optical network topology 43. The output of the flow assignment for the optical network 46 is a simulated packet
20   transport network 48 comprising information regarding data flow and bandwidth capacity for the optical network so as to create a basic optical capacity 47 for optical links in the simulated packet transport network 48.

The three supplied inputs, the packet network
25   topology 42, the packet traffic matrix 41 and the optical network topology 43 are generated using appropriate information relevant to the packet and optical networks and the type of traffic being transmitted on the simulated packet transport network 48. For example, the optical
30   network topology 43 may contain information such as a number of inputs and outputs of the optical cross-connect switches or information such as physical lengths of optical links. Further examples include information such as a number of

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wavelength channels used for signal transmission or information such as granularity of optical bandwidth for optical links. The packet traffic matrix 41 contains information such as the total traffic between router pairs
5   in bits per second.

Figure 5 uses the example packet transport network 30 depicted in Figure 3 to further demonstrate the type of information supplied as inputs and the resulting information generated as outputs in the method described by the flow
10 chart of Figure 4. The packet network topology 42 contains information as described above that is dependent upon elements in the packet network 42A, for example the first and second routers 12,13. The packet traffic matrix 41 contains information as described above that is dependent
15 upon packet traffic flow inputs and outputs 41A,41B supplied to the first and second routers 12,13. The packet traffic matrix 41 represents the packet traffic flow that will pass through the packet network topology 42. A combination of the packet network topology 42 and the packet traffic matrix 41
20 is the simulated packet network. Flow assignment for the packet network 44 is represented by packet traffic flow capacities 36A,36B moving bi-directionally on the packet link 11. Flow assignment is based on data in the simulated packet network. The basic packet capacity 45 is represented
25 by the total capacity of each packet link in the simulated packet network. In the example of Figure 5, this is a sum of packet traffic flow capacities 36A plus 36B travelling on the packet link 11.

The optical network topology 43 contains
30 information as described above that is dependent upon elements in the optical network 43A, for example first, second and third optical mesh protection cross-connect switches 21, 22, 28. A combination of the optical network

topology 43 and the basic packet capacity 45 of the
simulated packet network forms the simulated packet
transport network 48. An example of the flow assignment for
a single optical link performed during the flow assignment

5   for the optical network 46 is packets 37A, 37B moving bi-
directionally on the first optical link 26. The flow
assignment is made based on data in the simulated packet
transport network 48. Similar flow assignments are made on
the first and second access links 33,34 and the second

10 optical link 27. The basic optical capacity 47 is
represented by the total capacity of each optical link in
the simulated packet transport network 48. In the example
of Figure 5, the total capacity 47A of the first optical
link 26 is the sum of the packet traffic flow capacities 37A

15 plus 37B. The basic optical capacity 47 of the simulated
packet transport network 48 is represented by the total
capacities 47A, 47B, 47C, 47D of the first and second
optical links 26, 27 and the first and second access links
33, 34 of the optical path between first and second routers

20 12, 13, respectively.

Figure 6A displays an example of a visual
interpretation of information supplied by the packet network
topology 42. In the example of Figure 6A there are 10 core
routers and 14 edge routers. Core routers are labelled 101

25 to 110 and edge routers are labelled A to N. Core routers
are connected to more than two other routers, whereas edge
routers are connected to a maximum of two other routers.

Figure 6B displays an example of a visual
interpretation of information supplied by the optical

30 network topology 43. In the example of Figure 6B there are
24 optical cross connect switches. One optical cross connect
switch is co-located with each of the 10 core routers and 14

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edge routers. The optical links are linked over physical fiber routes.

Figure 7 displays a flow chart containing steps of a first sub-process 50, which expand upon the single step

5 shown in Figure 4 of flow assignment for the packet network 44. An input 51 to the first sub-process 50 is the simulated packet network resulting from the combination of the packet network topology 42 and the packet traffic matrix 41. In general, the simulated packet network comprises

10 information regarding the topology of the packet network such as how many routers are in the packet network and information regarding physical router connections, as well as traffic flow information in and out of the simulated packet network.

15 An initial method step 52 of the first sub-process 50 involves setting bandwidth for all packet links of the input 51 to the first sub-process 50 to zero. Following the initial method step 52, a decision step 53 is required to ensure that three method steps 54,55,56 are performed for

20 each ordered pair of source-destination routers.

In a first method step 54, a shortest packet path is determined between a pair of source-destination routers, based on positional router information as contained in the packet network topology 42 and traffic information as

25 contained in the packet traffic matrix 41. In a second method step 55, a source-destination packet traffic flow, in some embodiments identified as a label switch path (LSP) traffic flow, is established over the shortest packet path as determined in the first step 54. In a third method step

30 56, bandwidth of each packet link traversed by the packet traffic flow is incremented by an amount equal to the capacity required by the packet traffic flow on that packet

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link. The three method steps 54,55,56 are performed for each ordered pair of source-destination routers. When the three method steps 54,55,56 have been performed for all router ordered pairs, as determined by the decision step 53,

5   there exists a raw capacity value for each packet link based on multiple packet traffic flows that occur on each packet link of the packet network. A further method step 57 is necessary which involves increasing bandwidth of the packet links in order to meet packet network engineering

10   guidelines. In this case, average occupancy of the packet link is an important packet network engineering guideline.

         In a particular embodiment of the invention, the first method step 54 of determining the shortest packet path may be performed using a MPLS technique known as Open

15   Shortest Path First Traffic Engineering (OSPF-TE). In a particular embodiment of the invention, the second method step 55 of establishing the source-destination LSP may be performed using a MPLS technique known as Reservation Protocol Traffic Engineering (RSVP-TE).

20   A typical value used for the average occupancy of the packet link is 50% in the further method step 57 of the first sub-process 50. More generally, the average occupancy of the packet link varies based on a user's requirement for a specific packet transport network.

25   In a particular embodiment of the invention, the establishment of the source-destination packet traffic flow in the second method step 55 of the first sub-process 50 is based on a gravitational model. Traffic flow gravitational models essentially use the product of metropolitan

30   populations divided by some weak function of physical distance between metro areas, such as the physical distance, a square root of the physical distance, or a constant.

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Figure 8 displays a flow chart containing steps of
a second sub-process 60, which expand upon the single step
shown in Figure 4 of flow assignment for the optical network
46. An input 61 to the second sub-process 60 is the
5   simulated packet transport network 48 resulting from the
combination of the optical network topology 43 and the basic
packet capacity 45 of the simulated packet network. In
general, the simulated packet transport network 48 comprises
information regarding the topology of the optical network
10 such as how many cross connect switches are in the optical
network, information regarding physical router-cross-connect
switch connections and placement of cross-connect switches
in the optical network, as well as traffic flow information
in and out of the simulated packet transport network 48.

15   An initial method step 62 of the second sub-
process 60 involves setting capacity for all optical links
of the input 61 to the second sub-process 60 to zero.
Following the initial method step 62, a decision step 63
ensures that additional method steps 64,65,66 are performed
20 for all packet links.

            In a first method step 64, a shortest optical path
between optical cross-connect switches supporting packet
layer routers must be determined. In a second method step
65, an optical connection is established to support the
25 packet link, wherein capacity of each packet link is a
capacity previously determined within the flow assignment
process described in Figure 7. In a third method step 66,
capacity of each optical link traversed by the optical
connection must be incremented by an amount equal to the
30 capacity required by the optical connection on that optical
link. The three method steps 64,65,66 are performed for all
packet links. When the three method steps 64,65,66 are
performed for all packet links, as determined by the

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decision step 63, there exists a raw capacity value for each
optical link based on multiple packet traffic flows that
occur on each optical link of the optical network. A
further method step 67 is necessary which involves
5   increasing capacity of the optical links in order to meet
optical network engineering guidelines. In this case,
occupancy of the optical link is an important optical
network engineering guideline.

In a particular embodiment of the invention, the
10   first method step 64 of determining the shortest path
constraint between two cross-connect switches may be
performed using a technique known as Open Shortest Path
First Traffic Engineering (OSPF-TE) based Automatically
Switched Optical Network (ASON) routing. In a particular
15   embodiment of the invention, the second method step 65 may
be performed using a technique known as Constraint-based
Routing Label Distribution Protocol (CR-LDP) based ASON
signalling.

In a particular embodiment of the invention, a
20   typical value used for the occupancy of the optical link is
95% in the further method step 67 of the second sub-process
60. More generally, the optical network engineering
guideline varies based on a user's requirement for a
specific packet transport network.

25   The resultant output of the main process 40 yields
two views of the network, a packet network view and an
optical network view. The packet network view allows a user
to determine how much bandwidth capacity has to be obtained
from the optical network, and from where, in order to
30   satisfy all of the packet network requirements. It is
desirable that the bandwidth capacity requirements
determined by the steps of the first sub-process 50 are

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expressed as a combined total of effective packet transport
bandwidth and required overhead bandwidth.

Overhead consists of wasted bandwidth incurred by
a network, additional bandwidth requirements based on
5   engineering rules that dictate how much bandwidth must be
set aside to handle traffic peaks, and additional protection
bandwidth requirements that must always be available in case
of a failure occurring in the network.

Similarly, the optical network view allows a user
10   to determine how much bandwidth capacity has to be
provisioned, such as how many wavelengths are used in the
optical network and where. It is desirable that the
bandwidth capacity requirements determined by the steps of
the second sub-process 60 for the optical network view are
15   expressed as a combined total of traffic carrying bandwidth
and required overhead bandwidth.

The simulated packet transport network 48 created
using the steps of the main process 40 of Figure 4 described
above meets general traffic requirements for communication
20   systems. This output can be used to perform different forms
of network analysis. For example, the simulated packet
transport network 48 can be used to examine network capacity
planning. Another example is that the simulated packet
transport network 48 output can be used to examine
25   protection requirements of the network. To evaluate
protection requirements a survivability analysis must be
performed.

Survivability is defined as a condition wherein
failure of any single optical link will not prevent the
30   packet transport network from meeting traffic carrying
requirements. In some embodiments, the survivability
analysis is performed assuming MPLS fast reroute protection

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in the packet network. In other embodiments, a survivability
analysis is performed assuming optical mesh protection in
the optical network. More generally, survivability analysis
can be performed using any desired form of packet link

5   protection in the packet network or the optical network.

Figure 9 shows a flow chart for performing the
basic steps of a survivability analysis process 100 for
packet link protection in either the packet network or the
optical network. For example, MPLS fast re-route in the

10   packet network or optical mesh protection in the optical
network. An input 101, in the form of the simulated packet
transport network 48 from the main process 40 of Figure 4 is
supplied to the survivability analysis process 100. A
location in the topology of the co-modelled packet transport

15   network is chosen for an optical link failure to be
simulated so that the survivability analysis process 100 can
be performed.

An initial method step 102 of the survivability
analysis process 100 requires that a protection mechanism be

20   established for router pair connections. For example,
packet links in the packet network or optical paths in the
optical network. Following the initial method step 102, a
decision step 103 is required to ensure that method steps
104,105,106 are performed for all optical links in the

25   optical network.

In a first method step 104, all affected optical
connections are switched to the protection mechanism
established in the initial method step 102. In a second
method step 105, capacity of each optical link traversed by

30   the protection mechanism is incremented and should include
sufficient capacity to meet packet or optical network
engineering guidelines. After the second method step 105 is

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completed initial conditions are restored 106 to the optical
network before advancing to a next specific optical link and
performing the same process. When all optical links in the
optical network have been analyzed in this manner, as

5   determined by the decision step 103, a further method step
107 of the survivability analysis process 100 involves
adding up the capacity requirements. The output of the
survivability analysis process 100 depends on what s user in
interested in investigating. For example, it may provide

10   the user a view of packet bandwidth requirements and a view
of optical link capacity requirements under both normal and
failure conditions, using packet link protection in either
the packet network or the optical network.

To perform packet link protection in the packet

15   network it is necessary to perform several additional steps
during the survivability analysis process 100. Referring to
Figure 10, there is shown a flowchart of a packet network
survivability analysis process 70, based on MPLS fast
reroute packet protection. An input 71, in the form of the

20   simulated packet transport network 48 from the main process
40 of Figure 4 is supplied to the packet network
survivability analysis process 70. A location in the
topology of the co-modelled packet transport network is
chosen for an optical link failure to be simulated so that

25   the packet network survivability analysis process 70 can be
performed.

An initial method step 72 of the packet network
survivability analysis process 70 requires that back-up
packet traffic flow tunnels be established for all packet

30   links of the input 71. Back-up packet traffic flow tunnels
are established in a manner that the packet links and the
back-up packet traffic flow tunnels do not share the same
optical links. Following the initial method step 72, a

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first decision step 73 is required to ensure that method
steps 74,75,76,77,78,79 are performed for all optical links.

In a first method step 74, a first optical link is
taken out of service. Following the first method step 74, a
5   second decision step 75, is required to ensure a nested
process of the method steps 76,77,78 is performed for each
packet link affected by the optical failure. In a first
method step of the nested process 76, all packet traffic
flows are switched from the packet link affected by the
10   optical failure to the back-up packet traffic flow tunnels
established in the initial step 72. In a second method step
of the nested process 77, a bandwidth of each packet link
traversed by back-up packet traffic flow tunnels is
incremented and should include sufficient bandwidth capacity
15   to meet packet network engineering guidelines. In a third
method step of the nested process 78, a capacity of each
optical link traversed by an optical connection supporting
the back-up packet traffic flow tunnel is incremented and
should include sufficient bandwidth to meet optical network
20   engineering guidelines. If a packet link on a current
optical link is not affected by the optical failure then
method steps 76,77,78 are skipped and the process advances
to the next packet link. When the second decision step 75
has ensured that all the method steps of the nested process
25   are completed, the nested process terminates. Initial
conditions are restored 79 in both the packet network and
the optical network before the first decision step 73
results in the process advancing to a next optical link to
repeat the method steps 74,75,76,77,78,79 starting at the
30   first method step 74. When all optical links have been
analyzed in this manner, as determined by the first decision
step 73, a further method step 80 of the packet network
survivability analysis process 70 involves adding up packet

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link bandwidth requirements and optical link capacity
requirements wherein bandwidth and capacity requirements are
rounded up to the nearest packet link and optical link
granularity increments, respectively. The output of the
5 packet network survivability analysis process 70 gives a
user a view of the packet bandwidth requirements and a view
of the optical bandwidth requirements under both normal and
failure conditions, using MPLS fast reroute protection.

In a particular embodiment of the invention,
10 packet link occupancy is maintained at 50% in the second
method step of the nested process 77 of the packet network
survivability analysis process 70. More generally, the
packet link occupancy varies based on a user's requirement
for a given packet transport network.

15   In a particular embodiment of the invention,
optical link occupancy is maintained at 95% in the third
method step of the nested process 78 of the packet network
survivability analysis process 70. More generally, the
optical link occupancy varies based on a user's requirement
20 for a given packet transport network.

In a particular embodiment of the invention,
packet link granularity is maintained at 155 Mbits/s and
optical link granularity is maintained at 10 Gbits/s in the
further method step 80 of the packet network survivability
25 analysis process 70. More generally, the packet link
granularity and the optical link granularity vary based on a
user's requirement for a given packet transport network.

Referring to Figure 11, there is shown a flowchart
of an optical network survivability analysis process 90
30 based on optical mesh protection. An input 91, in the form
of the simulated packet transport network 48 from the main
process 40 of Figure 4 is supplied to the optical network

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survivability analysis process 90. A location in the topology of the co-modelled packet transport network is chosen for an optical link failure to be simulated so that the optical network survivability analysis process 90 can be

5   performed.

An initial method step 92 of the optical network survivability analysis process 90 requires that protection tunnels be established for all optical connections in the input 91. Protection tunnels are established in a manner

10 that the working tunnels and the protection tunnels do not share the same optical links. Following the initial method step 92, a decision step 93 is required to ensure that method steps 94,95,96,97 are performed for all optical links in the optical network.

15   In a first method step 94, a first optical link is taken out of service. In a second method step 95, all affected optical connections are switched to a protection tunnel established in the initial method step 92. In a third method step 96, capacity of each optical link

20 traversed by the protection tunnel is incremented and should include sufficient capacity to meet optical network engineering guidelines. After the third method step 96 is completed initial conditions are restored 97 to the optical network before advancing to a next optical link and

25 performing the same process. When all optical links in the optical network have been analyzed in this manner, as determined by the decision step 93, a further method step 98 of the optical network survivability analysis process 90 involves adding up the optical link capacity requirements.

30 The output of the optical network survivability analysis process 90 gives a user a view of the packet bandwidth requirements and a view of the optical link capacity requirements under both normal and failure conditions, using

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optical mesh protection. The packet bandwidth requirements
of the co-modelled network remain unchanged, that is they
are the same for a survivable or non-survivable network,
when protection is provided by an optical mesh protection
5 method.

In a particular embodiment of the invention,
optical link occupancy is maintained at 95% in the third
method step of the optical network survivability analysis
process 90. More generally, the optical link occupancy
10 varies based on a user's requirement for a given packet
transport network.

In a particular embodiment of the invention,
optical link granularity is maintained at 10 Gbits/s in the
further method step 98 of the optical network survivability
15 analysis process 90. More generally, the optical link
granularity varies based on a user's requirement for a given
packet transport network.

In some embodiments of the invention, the software
known as Netcalc is used to generate the packet network
20 topology 42, the optical network topology 43, the packet
traffic matrix 41 and provide flow and capacity assignments
for the packet network 44 and optical network 46 as depicted
in Figure 4. Netcalc is a capacity planning tool used for
design and simulation of multi-layer wide area mesh networks
25 both in the packet network and the optical network. Netcalc
can simulate networks with over 1000 nodes, one million
traffic flows, and 128 traffic classes. Netcalc can
simulate many topologies such as hub-and-spoke, ring, fully-
connected mesh. Netcalc can also simulate networks using a
30 variety of routing algorithms.

In some embodiments of the invention, the software
known as Netcalc can also be used to perform the packet

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network survivability analysis process 70 and the optical
network survivability analysis process 90 as shown in
Figures 10 and 11. In other embodiments software modules
are created for use within Netcalc to perform the various
5   described steps of the main process 40 and the packet
network and optical network survivability analysis processes
70,90.

Embodiments of the present invention provide any
computer language capable of developing software to perform
10 mathematical calculations to be used to generate co-
modelling analysis programs based on the main process 40 of
Figure 4. Embodiments of the present invention provide any
computer language capable of developing software to perform
mathematical calculations to be used to generate
15 survivability analysis programs based on the packet network
and optical network survivability analysis processes 70,90
of Figures 10 and 11.

Embodiments of the present invention provide the
co-modelling analysis programs based on the main process 40
20 of Figure 4 and survivability analysis programs based on the
packet network and optical network survivability analysis
processes 70,90 of Figures 10 and 11 to be stored on a
computer useable medium such as a floppy disk, a computer
hard-drive, a CD-ROM or any other conventional memory
25 storage device.

Numerous modifications and variations of the
present invention are possible in light of the above
teachings. It is therefore to be understood that within the
scope of the appended claims, the invention may be practised
30 otherwise than as specifically described herein.